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Risk of Navigation for Marine Traffic in the Malacca Strait using AIS

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Abstract

The Malacca Strait experiences high-density vessel traffic, and therefore is a busy area with high potential for collisions. Analyses of marine traffic that reflect the real conditions of ship navigation are performed to enhance maritime traffic safety. An automatic identification system (AIS) allows for the accurate investigation of actual ship encounters, ship collisions, and sea traffic management systems. For this study, an AIS receiver installed at the Universiti Teknologi Malaysia (UTM) provided AIS data, which focused on a selected area in the Malacca Strait. The 1972 International Regulations for Preventing Collisions at Sea (COLREG) guided the assessment of navigation safety based on real conditions using AIS and geographic identification systems (GIS). Based on estimates of the probability and consequence indices from a risk matrix, the time and encounter conditions determined the level of risk. This study also conducted safety measurements. The analysis indicated that ship safety would improve significantly if the vessels followed the guidelines established in this study.

Keywords: Risk of navigation, Ship collision, Malacca Strait, AIS

1. Introduction

The Malacca Strait is a vital strategic region for seaborne trade. However, it is a high-risk area for navigation because collisions are a major safety concern in many seaports. To enhance navigational safety, the analysis of marine traffic safety in the Malacca Strait is crucial. The Malacca Strait is the longest strait in the world, used for international navigation. It has long been an important trade route linking the Indian Ocean to the South China Sea and the Pacific Ocean. The Malacca Strait is located between the east coast of Indonesia's Sumatra Island and the west coast of Peninsular Malaysia, and links with the Strait of Singapore at its southeast end. The Malacca Strait extends from its

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northwest extremity at Ujung Baka, Sumatra (5°40’N, 95°26’E) by a line to its south extremity at Laem Phra Chao, Koh Phukit Island, Thailand (7°45’N, 98°18’E). The strait extends across its southeastern portion by a line between Tahan (Mount) Datok (1°20’E, 104°20’N) and Tanjung Pergam (1°10’E,104°20’N) (Thia-Eng C et al., 2000).

The increase in international shipping associated with the development in East Asia has resulted in increasing traffic through the Malacca Strait, which poses significant risks to the biodiversity and the marine environment, the livelihood of the coastal communities, and the fishing and tourism industries. An examination of the casualty data in the Malacca Strait between 1975 and 1995 shows the serious accidents primarily occurred in the high-density traffic regions (Gran S et al., 1999). Therefore, current safety measures require improvement and the subsequent support with relevant complementary services to face the challenges of increased maritime traffic.

The three littoral states of Indonesia, Malaysia, and Singapore have been cooperating since the early 1970s to enhance navigational safety in the Malacca and Singapore Straits. These three states proposed various measures to enhance navigational safety and environmental protection, which the international maritime organization (IMO) adopted. The IMO-adopted measures in the Malacca and Singapore Straits include the following: sea lanes and traffic separation schemes (TSSs), vessel traffic systems, mandatory ship reporting systems, and routing measures such as under-keel clearance requirements and deep-water routes.

Regulation 19 of SOLAS, Chapter V—carriage requirements for ship-borne navigational systems and equipment—requires navigational equipment to be carried on board ships according to the ship type. As part of a revised Chapter V, IMO adopted a new requirement for all ships to carry AISs capable of automatically providing information about the ship to other ships and to coastal authorities.

In this study, an AIS is implemented to assess the risk of ship collision under COLREG guidelines. In this context, the AIS is implemented as a source of data and is the input for the risk assessment.

2. Literature review

Several authors have published risk assessments for ship collisions in the channel. Qu X et al (2011) studied ship collision risks in the Singapore Strait. In this study, real-time ship locations and sailing speeds provided by Lloyd’s MIU AIS enable an estimate of three risk indices for the Singapore Strait. Mou et al (2010) used AIS data to study collision avoidance in busy waterways by performing statistical analyses of ships involved in collisions, establishing the risk assessment model via the SAMSON program. For this model, the authors only took into account the ships (own ships) that encountered a TSS in the port of Rotterdam. Pedersen et al (2002) introduced a model to calculate the collision risk in a congested shipping lane by the following steps: first, investigate the distribution of different categories of traffic; second, determine the individual geometrical collision diameter; and third, integrate the number of encounters. Otto et al.(2002) discussed the risk of collision and grounding for a RoRo passenger ferry. In this study, the consequences of collision and grounding scenarios were estimated by introducing damage criteria that link the calculated distribution of damage size and location to monetary units. Jiacai et.al (2012) established a visualization model that assesses maritime traffic based on the ship’s AIS data. In this paper, we propose a novel visualization model to assess the maritime traffic situation based on a ship’s AIS. Wang et al. (2010) explored the formal safety assessment (FSA) of containerships. In their study, they used fault tree analysis (FTA) for hazard identification and risk evaluation. Kobayashi et al. (2008) presented guidelines for ship evacuation during a tsunami. To do so, they analyzed AIS data from a ship that passed in Osaka Bay, Japan. Pitana et al. (2010) analyzed the evacuation of a large passenger vessel in the case of a pending tsunami using a stochastic approach, a discrete event simulation (DES). In this study, they obtained AIS data for calculating the sea traffic in the area. Zaman et al. (2013) examined the maritime safety in the Malacca Strait using AIS data and an analytic hierarchy process (AHP). This data enabled the ranking of situations based on a score that measured danger. Zaman et al. (2013) established the ship collision using FMEA FUZZY based on its AIS data. The probability calculation took into account the traffic density in the channel.

This study focuses on the use of AIS and GISs to establish a safety protocol for navigation. Risk assessments, including probability and consequence analyses, are conducted. The risk analysis determined under different conditions and times originated from AIS data from an AIS receiver system, which Kobe University installed at UTM Malaysia. Three conditions comprised the risk analysis: head-on, crossing, and overtaking.

3. AIS data Collection

a. Overview of AIS

The actual sea traffic conditions of the Malacca Straits were recorded by an AIS data receiving system installed in the UniversitiTeknologi Malaysia (UTM). The equipment was used to collect the data. All AIS data received by the equipment were continuously and automatically stored on the hard disk of a PC.The AIS is designed to transmit and receive information about a vessel. This information includes its identity, position, speed, and course, along with other relevant information. Vessels within AIS range can receive information transmitted by other vessels and display this information on a dedicated AIS display, or a PC using navigation software. Combined with a shore station, this system also offers port authorities and maritime safety bodies the ability to manage maritime traffic and reduce the hazards of marine navigation.

The AIS system is designed to recognize and monitor ship weighting more than 300 gross tons (GT) that are engaged in international travel, and ships of 500 GT or more that are travelling domestic routes. Both static and dynamic ship data can be displayed. Dynamic information on each vessel is updated every 2-10 s depending on the speed of the vessel.

The static information consists of the vessel's maritime mobile service identify (MMSI), the name of the vessel, its call-sign, length, maximum ship draft, IMO number, ship beam, ship type, and antenna position. The dynamic information recorded includes longitude, latitude, current time, course, rate of turn, overground speed, various navigation information, current ship draft, destination, and type of cargo.

b. AIS Data Analysis

The study area of this research is shown in Fig.1. Based on AIS data investigation, it shows the most data per day were on Mei 2010, when the number of ships was 285. That is also shows that the number of ships tends to rise on 05/04/2010 before declining from 05/05/2010.

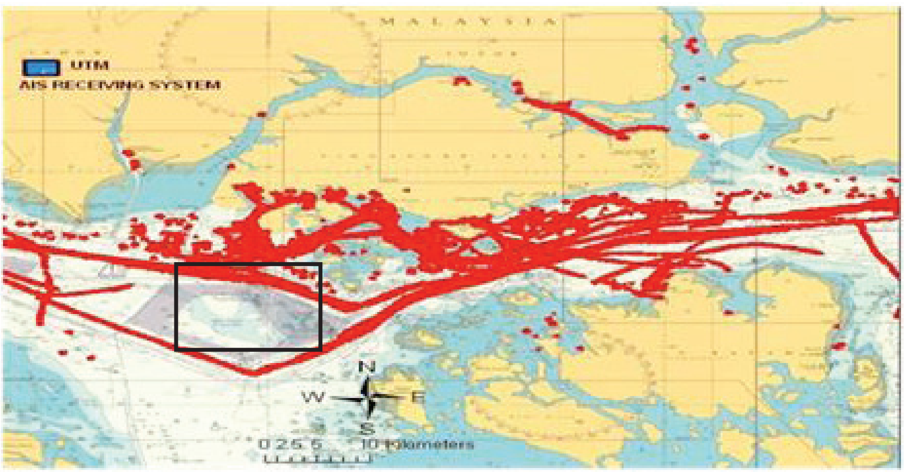

Fig.1. study area and tracking of ship based on AIS

4. Safety of navigation assessment

a. Ship collision probability

Data from the AIS and GIS enable risk assessment, which are obtained from analyzing the probability and consequences. Based on AIS and GIS data, the risk analyses are categorized into three parts: head-on, crossing, and overtaking. The risk analysis is composed of two main activities: probability modeling and consequence modeling. In this study, collision probabilities were established based on AIS data and hazard analysis. The factors analyzed in assessing the ship collision probability are the following: head-on, crossing, and overtaking conditions, as well as the traffic density, which was based on AIS and GIS data. The traffic density is determined as ;

$$\rho_{s}= \frac{N_m}{D_c \, x \, W_c}, \tag{1}$$

where N_m is the number of ships using the channel, D_c is the channel length, and W_c is the channel width. Figure 1, based on AIS and GIS data, shows the area selected to calculate the traffic density and ship collision probability.

The ship collision probability per passage is expressed as:

$$P_a = N_i \, x \, P_c \tag{2}$$

where Ni is the probability number of collisions per passage and $P_c$is the failures per passage or encounter. P_c can be expressed as

$$P_c = \mu_c \, x \, T \tag{3}$$

where μ_c is the failures per hour and *T* is the time taken per passage.
The probability number of collisions in the head-on and overtaking conditions per passage are expressed as

$$N_i = 4 \, x \, B \, x \, D \, x \, \rho_s \tag{4}$$

The number of collisions in the crossing condition per passage is:

$$N_i = 2 \, x \, D(L + B)\rho_s \tag{5}$$

In Equations 4–5, *B* is the mean beam of meeting (m), *L* is the mean length of meeting (m), *D* is the sailing passage distance, and N_m is arrival frequency of meeting ships (ships/time). In this study, Equations 3–5 are used based on AIS and GIS data. The number of collisions per year can then be determined as

$$\text{Na} = \text{Pa} \times (365 \times 24 / \text{T}) \tag{6}$$

Tables 2–4 show estimates of ship collision probabilities in selected areas of the Malacca Strait. Tables 2–4 also show *Nm*, the arrival frequency of meeting ships. In this case, *Nm* is determined based on AIS and GIS data, and *Ni* is calculated according to Equations 4 and 5.

Based on AIS data, the probability assessment scenario was carried out using different times with actual data in the selected area, as shown in Fig. 1. In this case, the scenarios taken have high traffic areas, at 02:00, 10:00, and 22:00. The result of probability assessment is classified in Tables 2–4.

Table 1. Probability index and consequence categories

Probability Index	Description		
1	Very unlikely	Less than once per 1000 years	P < 1/1000
2	Remote	Once per 100–1000 years	P < 1/100
3	Occasional	Once per 10–100 years	P < 1/10
4	Probable	Once per 1–10 years	P < 1
5	Frequent	More than once per year	P = 1
Consequence categories	Description		
A	Does not result in injuries		
B	Minor injuries		
C	Major injuries		
D	Death or total disability		
E	Death or total disability for several people		

The results of the risk assessment should be tailored to the probability and consequence index categories that exist in Table 1. Then the results of table 1 is used to create a risk matrix. For the probability index, Point 1 shows very unlikely, where the possibility of accidents occur less than once in 1000 years, with the number probability is P <1/1000.

Then the number 2, indicating the remote, which means the possibility of an accident occurring once per 100 to 1000 years, with the value of probability is P <1/100. At point 3 probability index, Occasional means the likelihood of accidents occurring once per10-100 years, with the value of probability is P <1/10. Point 4 on probability index means Probable. In this context, the possibility of accidents occur once per 1-10 years, with the value probability is P <1. There are frequent at points 5, where the accident occurred more than once per year, where P = 1.

For consequence categories, classified into 5 categories with symbols A, B, C, D, E. where A means does not result in injuries, B means minor injuries, C is major injuries, D means death or total disability and E is death or several total disability for people. In determining the consequence should be in accordance with the severity of which occurred in the accident.

Determination of probability and consequence is based on accurate data from AIS. The condition analysis of traffic carried by AIS convert the data into a GIS, so that the condition of traffic in the Strait of Malacca can be visible and legible. It can thus be determined probability and its consequence. Results of the adjustment table 1 was then plotted on a risk matrix to determine the level of risk existing in the Malacca Strait in accordance with the specified time. Determination hour traffic congested ship determined in accordance with the AIS data.

Table 2. Collision probability based on AIS data at 02:00

Node		N_m	ρ_s	N_i	μ_c	$D_c(m)$	*L (m)*	*B(m)*	*T*	P_c	P_a	*P*
1	Ship Head-on	12	4.4321E-08	0.1313	2E-05	24688	180	30	1	1.5E-05	1.96953E-06	0.207
2	Ship Overtaking	15	5.5401E-08	0.16413	2E-05				1	1.5E-05	2.46192E-06	0.323
3	Ship Crossing	36	1.3296E-07	1.37867	2E-05				1	1.5E-05	2.06801E-05	6.521
	Total	63									8.37051E-06	

Table 3. Collision probability based on AIS data at 10:00

Node		N_m	ρ_s	N_i	μ_c	$D_c(m)$	*L (m)*	*B(m)*	*T*	P_c	P_a	*P*
1	Ship Head-on	25	9.2334E-08	0.27355	2E-05				1	1.5E-05	4.10319E-06	0.895
2	Ship Overtaking	35	1.2927E-07	0.38296	2E-05				1	1.5E-05	5.74447E-06	1.761
3	Ship Crossing	68	2.5115E-07	2.60416	2E-05	24688	180	30	1	1.5E-05	3.90624E-05	23.268
	Total	128									1.63034E-05	

Table 4. Collision probability based on AIS data at 22:00

Node		N_m	ρ_s	N_i	μ_c	$D_c(m)$	$L\ (m)$	$B(m)$	T	P_c	P_a	P
1	Ship Head-on	19	7.0174E-08	0.2079	2E-05				1	1.5E-05	3.11843E-06	0.519
2	Ship Overtaking	26	9.6028E-08	0.28449	2E-05	24688	180	30	1	1.5E-05	4.26732E-06	0.972
3	Ship Crossing	48	1.7728E-07	1.83823	2E-05				1	1.5E-05	2.75735E-05	11.59
	Total	93									1.16531E-05	

b. Consequence assessment

The consequence analysis for each scenario was carried out. Five categories comprise the built risk level by using a risk matrix. Table 1 shows the probability index and the consequence categories. The consequence analysis is classified as the following: does not result in injuries, minor injuries, major injuries, death or total disability, and death or total disability of several people. The results of the consequence analysis are plotted as a risk matrix.

c. Constructing risk matrices

Figures 2, 3, and 4 show the risk matrices for probability and consequence analyses in the Malacca Strait based on AIS and GIS data. Based on AIS data, the scenario of probability assessment was carried out with different times using actual data. In this case, the scenarios taken in the following times have high traffic areas: 02:00, 10:00, and 22:00. Figure 2 shows the risk matrix at 02:00, based on AIS data. In this case, the risk matrix is established based on the results of the probability and consequence assessments. In this condition, the number of ships in head-on encounters is 12, in crossing encounters is 15, and in overtaking encounters is 36.

The numbers of ships is determined based on AIS data in the selected area in the Malacca Strait, as shown in Fig. 1. Based on the probability index, the head-on, crossing, and overtaking encounters are classified, respectively, at points 4, 4, and 5. Based on the consequence analysis, the head-on, crossing, and overtaking encounters are classified, respectively, at points C, C, and D. The tolerable conditions are for the head-on and crossing encounters. An intolerable condition is the overtaking encounter.

Figure 3 shows the risk matrix at the 10:00 scenario based on AIS for which the risk level was established in the head-on, crossing, and overtaking conditions. Based on AIS data, the number of ships in head-on conditions is 25, crossing conditions is 35, and overtaking conditions is 68. Based on the probability index, the head-on, crossing, and overtaking conditions are classified, respectively, at points 4, 5, and 5. In addition, based on consequence analysis, head on, crossing and overtaking are classified, respectively, at point C, D, and D. In this case, risk level conditions are the following: a tolerable level for head-on, an intolerable level for crossing, and an intolerable level for overtaking.

Figure 4 shows the risk matrix at 22:00 based on AIS data. The risk level was established in the head-on, crossing, and overtaking conditions. In these conditions, the number of ships in head-on is 19, in crossing is 26, and in overtaking is 48. The risk level conditions are the following: a tolerable level for head-on, a tolerable level for crossing, and an intolerable level for overtaking. The results of navigation safety based on risk assessments using AIS data for different times are important for navigators to observe if in transit in this area. These results are also useful to ensure safety measures and risk mitigation for enhancing safety in the Malacca Strait.

		1	2	3	4	5
	A	N	N	N	N	T
Consequence	B	N	N	N	T	T
	C	N	N	T	T(H,C)	I
	D	N	T	T	I	I(O)
	E	T	T	I	I	I

N = Negligible
T = Tolerable
I = Intolerable

Fig. 2 Risk matrix based on AIS data at 02:00

Consequence

	1	2	3	4	5
A	N	N	N	N	T
B	N	N	N	T	T
C	N	N	T	T(H)	I
D	N	T	T	I	I(C,O)
E	T	T	I	I	I

N = Negligible
T = Tolerable
I = Intolerable

Fig. 3 Risk matrix based on AIS data at 10:00

Consequence

	1	2	3	4	5
A	N	N	N	N	T
B	N	N	N	T	T
C	N	N	T	T(H,C)	I
D	N	T	T	I	I(O)
E	T	T	I	I	I

N = Negligible
T = Tolerable
I = Intolerable

Fig. 4 Risk matrix based on AIS data at 22:00

5. Risk Control Option (RCO)

This step aims at proposing an effective and practical RCO or safety measure. High-risk areas are identified from the information obtained in the risk assessment, and then, the development of risk control measures can be initiated. Risk control measures can assist in reducing the occurrence likelihood of failures and/or mitigating their possible consequences. Structural review techniques may be used to identify all possible risk control measures for cost-effective decision-making. The RCO are generated from the results of the risk assessment, which is established based on AIS data, as shown in Figs. 2–4. Table 5 shows the safety measures adopted to reduce risk during ship collision.

Table 5. Risk Control Option of ship collision

Accident	Hazard		Probability/Consequence		Risk	RCO to reduce risk
	Event	Causes	Probability	Consequence		
Collision	Human error	Fatigue&lack of or knowledge&skills	Frequent	Death/disability	Intolerable	Increase knowledge & skills & promote culture of safety
	Ship Conditions	Type of ships, length, speed, state of loading	Probable	Death/disability	Tolerable	Replace old ships with new ships and conduct careful examinations of the ships conditions
	Environmental Factors	Distance between vessels is close	Probable	Major injury	Tolerable	Make navigational aids available
	Machinery factors	Failure of main engine or electronics	Probable	Major injury	Tolerable	Conduct regular maintenance
	Navigational factors	Inappropriate crew manning	Probable	Major injury	Tolerable	Increase crew manning capabilities

6. Conclusions

A study on navigation safety using AIS data in the Malacca Strait was conducted. The AIS was implemented as a source of data for hazard identification and ship collision probability for the risk assessment step in the FSA.

Based on the AIS data, the ship population passing through the Malacca Strait on 5/4/2010 was calculated. The type of ships passing through the Malacca Strait was as the follows: 46% tanker ships, 27% cargo ships, 8% tugs, 8% passenger ships, 5% LNG, and 5% other ships.

Based on AIS data, the risk assessment scenarios were carried out with different times using actual data. The risk level was established in the head-on, crossing, and overtaking conditions. The scenarios were assessed during times in which the strait had high traffic: at 02:00, 10:00, and 22:00.

In the future, the establishment of a cost benefit analysis and a recommendation of decision-making will further enhance the safety in the Malacca Strait.

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